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Soft Rot of Sweet Potatoes and Its Control

Robert H. Daines

New Jersey Agricultural Experiment Station
Rutgers University
New Brunswick, N. J.

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SUMMARY

Since the preparation of this manuscript the Federal Commissioner of Food and Drugs has advised us that, although no adequate data are available on whether the amount of borax present as a residue on treated potatoes is injurious to human health, an attitude of caution on the question must be adopted. It is therefore necessary, for the present, to advise against using boron on sweet potatoes that are to be eaten.

The data recorded in this paper, and data presented elsewhere and referred to here, show that:

Soft rot of sweet potatoes may produce serious losses during storage or during the poststorage period.

Soft rot may be caused by nine species of Rhizopus, *R. nigricans* being the most common.

Soft rot may be produced over a temperature range extending from 38° to 107.6° F. The optimum range for *R. nigricans* infection is between 65° and 73.4° F. The optimum humidity for infection at a temperature of 73.4° F. is between 75 and 84 per cent.

Prevention of soft rot during storage can best be accomplished by maintenance of a clean storage house and hampers; exclusion of all rodents from the storage house; avoidance of frost injury and sun-scalding of the potatoes; care in handling the sweet potatoes at harvest time and at the time of their storage; and maintenance of proper temperatures and humidities during the curing and storage periods.

Temperatures varying from 80 to 85° F. and a relative humidity of about 90 per cent are recommended for the curing period, which should be about 10 days to 2 weeks in length. At such temperatures and humidities wounds are healed and thereby made resistant to soft rot infection by the development of wound cork layers.

Following the curing period, sweet potatoes should be stored at a temperature of about 55° F. and a relative humidity of 85 to 90 per cent.

Chemical treatments applied to the potato have not been proved to be of value in preventing soft rot during the storage period.

The methods of cleaning and handling sweet potatoes following the storage period, influence greatly the amount of soft rot to develop during the marketing period. The more bruising or scratching that occurs, the greater the risks from soft rot become.

Dipping the sweet potatoes in a solution of 20 pounds of borax in 100 gallons of water, following storage, was found to reduce significantly the amount of soft rot to develop during the poststorage period. For maximum effectiveness this treatment should be made as soon as possible following the cleaning of the potatoes, preferably during the first 36-hour period. Since the

borax solution weakens on use, it is recommended that a 50-gallon batch of dipping solution be discarded after it has been used to treat about 300 bushels of sweet potatoes.

Although the solution of sodium borate gives good protection against soft rot, the addition of 10 pounds of sodium hydrogen carbonate to each 100 gallons of dipping solution and enough emulsified oil to give about 1.75 per cent actual oil in the dipping material, improves the appearance of some sweet potatoes.

Soft Rot of Sweet Potatoes and Its Control

ROBERT H. DAINES, *Associate Plant Pathologist*

Soft rot, caused by several species of Rhizopus, is the most destructive postharvest disease that affects the sweet potato in New Jersey. Serious losses from decay may occur during the storage of improperly cured and poorly stored potatoes, and diseased sweet potatoes are occasionally found in the field at harvest time, but in New Jersey the heaviest losses come during the period between the removal of the potatoes from storage and the time they are consumed.

Symptoms

Soft rot is caused by a fungus which is capable of rotting the sweet potato with extreme rapidity. It is not unusual for a large part of an apparently sound potato to become soft and watery in one day.

Affected potatoes are so soft that they crush easily when handled. At this stage, the decayed tissue is water-soaked, and when it is squeezed, a straw-colored solution runs out. If the skin ruptures while the disease in in progress the fungus responsible for this decay may produce a superficial white cottony growth which darkens with age. If the decayed sweet potatoes are left undisturbed they gradually lose moisture until they finally become shriveled mummies. Storage houses in which the rot is present usually have a wine-like odor together with an unusually large number of fruit flies.

The Causal Fungi

Although *Rhizopus nigricans* is the most common pathogene associated with sweet potatoes exhibiting soft rot, eight other species of this genus; namely, *R. tritici, R. nodosus, R. maydis, R. reflexus, R. artocarpi, R. delemar, R. arrhizus,* and *R. oryzae,* have been demonstrated by Harter, Weimer, and Lauritzen (5) as being responsible for a similar type of decay. Harter and Weimer (6) have also shown that these fungi can produce a similar decay of a large number of fruits and vegetables under suitable environmental conditions.

Lauritzen and Harter (9) have demonstrated that *R. nigricans* will infect the sweet potato over a temperature range of 38° to 86° F., the optimum range for infection being between 65° and 73.4° F., and that the whole group of destructive Rhizopus species will produce infection over a temperature range of 38° to 107.6° F. These same investigators (10) found that the optimum relative humidity for infection of halved roots, at a temperature of 73.4° F., was 75 to 84 per cent. The percentage of infection decreased rapidly when the humidity was above or below this range. Very few infections occurred at relative humidities above 93 per cent at a temperature of 73.4° F. In this series of experiments it was also learned that halved roots that were subjected to high relative humidities and a temperature of 73.4° F. for 4 to 12 days

showed resistance to soft rot regardless of whether they were retained in high-humidity exposures or transferred to low-humidity chambers. On the other hand, halved roots held at a low humidity for 4 to 12 days decayed badly when they were transferred to high-humidity chambers.

Control

Control of soft rot resolves itself into two distinct problems: first, prevention during the storage period; and second, control between the time of removal of the sweet potato from storage and the time of consumption.

Prevention During Storage

Sanitation.—Since soft rot is caused by a fungus, it is important that measures be taken to keep the fungus population in a storage house at a minimum. This can best be done by maintaining a clean, dry, well-aerated house. Organic matter refuse, especially decaying sweet potatoes, should not be allowed to remain in the storage house. This does not mean that decaying sweet potatoes should be sorted out during the storage period, for such a procedure will greatly increase the losses from decay (15). It is suggested, however, that loose potatoes be avoided in the storage house because such potatoes are likely to be bruised through rough usage and thereby be made unusually susceptible to soft rot. Rats and mice should also be kept from the storage house, as potatoes injured by their feeding activities are likewise very susceptible to soft rot.

Where serious difficulty has been experienced with rot, the storage house should be fumigated with a mixture of 3 pints of formaldehyde and 23 ounces of potassium permanganate for each 1000 cubic feet of space (2,4,8), before the next crop is stored. During the fumigation all windows and doors of the storage house should be kept closed for at least 24 hours. Following the fumigation period the house should be aired thoroughly before it is used for storage.

Since formaldehyde gas is extremely irritating to the eyes and nasal passages, it is important that precautions be taken against injury to the fumigators. Such injury can best be avoided by a well-planned and well-executed fumigation procedure. In preparing to fumigate, it is a good practice to place several large containers at various places in the house. Into each, put a weighed amount of potassium permanganate crystals. Alongside, place a measured amount of formaldehyde, corresponding with the ratio given above, in containers that can be quickly emptied. Beginning at the container farthest from the exit door, pour the formaldehyde on the permanganate crystals in each container as quickly as possible. The reaction between these two chemicals is very vigorous, and unless the container is large, the liquid will boil over on the floor. Baskets that are to be reused for harvesting and storage should be placed in the storage house prior to the fumigation.

Care in Handling.—Investigations have shown that the fungus responsible for soft rot gains entrance to the sweet potato through injuries to the skin

that have not healed (7, 16, 17). Fresh wounds are more easily infected than old unhealed wounds (10). According to the U. S. Department of Agriculture (16), "Any break in the skin affords a place for disease to get started, and the mere drying of the white juice in a cut or wound does not effectively close the wound against disease."

It is very important, therefore, that sweet potatoes be harvested and placed in storage with a minimum of mechanical injury. Careful handling reduces not only the likelihood of disease, but also the loss from shrinkage. Thompson and Beattie (15) have reported that during a 4-month storage period carefully handled sweet potatoes lost 7.52 per cent from shrinkage, whereas commercially handled potatoes lost 10 per cent. These investigators also reported that losses from decay amounted to 0.45 per cent for the carefully handled lot in comparison with 3.0 per cent for the commercially handled lot. These results are in accord with data obtained in New Jersey during the storage season of 1941-42. At harvest time 3 bushels of sweet potatoes were dug with a fork, extreme care being taken to avoid cutting or bruising. At the same time 3 bushels were harvested without special care from the adjoining row with a white-potato digger. Both lots were stored, in baskets, in the same sweet potato storage house for approximately 5 months. During this period the carefully handled potatoes lost 11 per cent from shrinkage and 0.4 per cent from rots, whereas the other lot lost 16 per cent from shrinkage and 5.1 per cent from rots (mostly soft rot).

In addition to mechanical injuries, sun-scorching or frosting of potatoes should be carefully avoided.

Chemical Treatment.—Although careful handling of sweet potatoes during harvesting is a valuable aid in preventing soft rot in storage, such care cannot provide potatoes for storage that are entirely free from mechanical injuries. Hence other measures must be used to supplement this precaution. Stuckey (14) reports that one such method investigated by him was to dip freshly dug potatoes in either a solution of 1 pint of formaldehyde in 40 gallons of water, or a 5-5-50 bordeaux mixture suspension. These treated potatoes were then stored in banks for 4 months at which time they were removed and examined. No control was noted. Later, Poole investigated the value of nonpoisonous disinfectants applied as dusts or dips (13), and found that 8-8-50 bordeaux mixture, lime, copper carbonate, and monohydrated copper sulfate were effective in soft rot prevention, whereas sulfur, boric acid, lysol, and potassium permanganate were less effective. In these tests the amount of soft rot that developed even in the untreated lots was low, and as suggested, the difference in performance may have been partly due to the mice-repelling properties possessed by the copper and lime treatments.

In a prestorage dip experiment conducted in New Jersey it was found that potatoes dipped in sodium borate (20 pounds in 100 gallons of water) shrivelled excessively. Of the other materials tested, tetrachloro para benzoquinone, tumaric acid, and bordeaux mixture, none proved to be better, from the standpoint of shrinkage or disease control, than the untreated check.

Curing.—The most satisfactory and generally used measure of preventing soft rot during storage is to control the storage temperature and humidity during the curing period in such a way that the wounds will become resistant to Rhizopus invasion as quickly as possible.

In a discussion on the storage of sweet potatoes by Thompson, which was later revised by Boswell and Beattie (16), the following significant statement occurs:

> Most sweet potato rot organisms rarely infect sweet potatoes through the sound, unbroken skin. A cut or broken place will actually heal under proper conditions by the formation of new cells which are much like the cells of the skin in their ability to prevent infection. These new cells form a layer just beneath the wound, and because of the corky nature of this layer it is commonly called wound cork. Workers in this Department have proven by several tests that this wound cork layer greatly retards infection and to a large degree actually prevents it. The wound cork layer is formed beneath the dried and hardened surface that soon develops over a wound, but it is formed only under certain favorable conditions . . . The mere presence of a dried and hardened surface over a wound is no indication that it has been healed by a layer of wound cork beneath. The dry, hardened surface of a wound may offer slight resistance to infection, but it is too little protection to afford safety.

Since the fungi which cause nearly all storage diseases infect potatoes chiefly through unhealed wounds, it is important that potatoes be stored under conditions that will insure wound cork formation. Investigations (1, 10, 12, 17) have been made to determine the most favorable conditions for this healing process. The most significant fact found during these investigations is that wound cork formation or healing proceeds most rapidly at the temperatures that have been recommended, for years, for proper curing of sweet potatoes. At 89° F. and a relative humidity of 92 per cent, wound cork is well developed in 1 week. At lower or higher temperatures, or at lower humidity, it develops less rapidly. Even though the temperature is favorable, wound cork formation is greatly hindered if the air surrounding the sweet potatoes is as dry as 66 per cent.

During the curing period, which should last for 10 days to 2 weeks, the temperature should be maintained between 80 and 85° F. with a relative humidity of about 90 per cent. Only enough ventilation should be given to prevent condensation of moisture. According to Lauritzen and Harter (11), "The old idea of curing was that by driving off a lot of moisture sweet potatoes were protected against spoilage. The newer conception is to keep the potatoes in a moist atmosphere during curing so as to aid the healing process and to prevent excessive loss of moisture."

As soon as the curing period is over, the temperature of the storage house should be gradually reduced to approximately 55° F. This temperature should be maintained, as nearly as practicable, throughout the storage period. Temperatures below 50° F. should be avoided.

A relative humidity ranging from 85 to 90 per cent should be maintained throughout the storage period. Such high humidities tend to check shriveling, and to protect the potatoes still further against soft rot infection.

Poststorage Control

The common practice in New Jersey on removal of sweet potatoes from storage, is to clean the potatoes by brushing, after which they are graded in preparation for shipment to market. In a few instances the potatoes are cleaned by a short immersion in a vat of water, after which they are dried and packed for shipment. Either of these procedures, while cleaning the sweet potatoes, produces numerous small breaks in the skin. Such injury is accentuated by the somewhat brittle nature of the skin of a sweet potato that has been stored. Because of the jostling and frequent handling that potatoes undergo during transit and on the market, and because of the low temperatures and humidities to which they are exposed during this period, these breaks are not healed over by a callous layer. The cleaning and packing procedures not only produce breaks in the sweet potato skin, which provide the open doors to the invading soft rot organism, but they serve to spread the fungus spores from diseased to healthy sweet potatoes. Perhaps this accounts for the serious rot losses that are experienced occasionally during the period between the removal of the sweet potatoes from storage and their consumption (3).

In the past, suggestions for soft rot control have consisted of measures to reduce losses during storage, but adequate control recommendations to prevent the occurrence of this disease during transit and on the market have not been generally available.

In the experiments reported here, an attempt was made to determine the effect of various methods of handling, following the storage period, on the amount of soft rot subsequently developing, and to find a nonpoisonous dipping material which would, by covering the potato with an invisible film, protect it from soft rot.

Methods of Handling.—In an experiment designed to show the influence of various methods of handling on the development of soft rot, sweet potatoes were cleaned by various methods, packed in baskets, and stored for 10 days at a temperature varying from 57 to 62° F. At the end of this period the potatoes (5 bushels per treatment) were examined and records taken on the amount of soft rot that had developed. Potatoes that had been cleaned by a brushing machine showed 57.42 per cent spoilage; those cleaned by hand, using rags, showed 21.06 per cent spoilage; those that had been graded and then dipped in water for cleaning revealed 11.75 per cent spoilage; whereas those that had been graded and packed without cleaning showed only 8.67 per cent spoilage from soft rot. From these data it appears that the amount of soft rot to develop is closely related to the harshness of the method employed in cleaning and handling the potatoes.

Protection by Dip Treatment.—In an attempt to find a dipping material that would provide protection against soft rot during the marketing period, various materials and combinations of materials were prepared as water solutions, suspensions, and emulsions. Sweet potatoes were removed from storage, brushed, and then dipped in the various materials, after which they

were packed into baskets while still wet, and stored at a temperature varying from 57 to 62° F. After 10 or 11 days the potatoes were examined for appearance and for soft rot. The results are shown in table 1.

In this investigation borax has consistently given more protection against soft rot than any other material tested. Copper fungicides not infrequently actually have increased the losses caused by soft rot. Sulfurs, both soluble and insoluble, and several organic fungicides, in the quantities used, have not proved equal to the task of preventing the occurrence of soft rot in treated potatoes.

Table 1

Results of Dip Treatments of Sweet Potatoes Conducted During the Storage Season of 1940-41 for Rhizopus Soft Rot Control

Materials Used	Total Number of Potatoes Treated	Percentage Developing Soft Rot
Borax, 20 lbs.; oil, emulsified or straight; sodium hydrogen carbonate ($NaHCO_3$), 10 lbs. water to make 100 gal.	4018	1.0
Sulfur, 8 lbs. sodium hydrogen carbonate, 10 lbs.; oil, emulsified or straight; water to make 100 gals.	506	31.5
Sulfocide, 1 gal.; oil, emulsified or straight; water to make 100 gal.	1351	17.2
Untreated check	1267	50.7

Note: Records taken 10 to 11 days after treatment.

In the tests reported in table 1 the fungicidal materials were admittedly favored by the packing and storing of wet potatoes that were not handled again until the disease counts were made. By such a procedure all breaks in the skin were coated with a fungicide when the sweet potatoes were stored, and because these were not handled again, the experiment was not complicated by further surface wounding.

In order to determine the value of the dip treatment under conditions more comparable with those that occur during transit and on the market, freshly brushed potatoes were dipped in either a borax solution or bordeaux mixture. These potatoes were allowed to dry partly, but while they were still moist they were repacked and hauled by truck from Landisville to New Brunswick, New Jersey, a distance of 90 miles. Upon their arrival in New Brunswick they were unloaded and held in a storage where the temperature fluctuated from 45 to 80° F. On the 11th, 15th, and 21st days after treatment these potatoes were examined for soft rot, and the rotted potatoes were removed. The results are shown in table 2 and in figures 1 and 2. In this experiment it was found that

although borax did not prevent soft rot nearly so completely as in the test reported in table 1, its value was still considerable. This is especially true for New Jersey sweet potatoes, because most of these are consumed during the first 2 weeks after they are removed from storage.

To determine the length of time the dip treatment could be delayed after the brushing of the sweet potatoes and still provide maximum protection, brushed potatoes were held at a temperature of 57 to 62° F. for varying lengths of time before being dipped and returned to storage in a wet condition. The results indicated that the sweet potatoes should be treated as soon as possible after the brushing. Even though the treatment proved beneficial at all times

Table 2

Results of Dip Treatments for Rhizopus Soft Rot Control of Sweet Potatoes Subsequently Hauled to Storage

Materials Used	Number of Days After Treatment	Total Number of Potatoes Treated	Percentage Developing Soft Rot
Borax, 20 lbs.; emulsified oil; sodium hydrogen carbonate, 10 lbs.; water to make 100 gal.	11	440	2.72
	15		4.56
	21		10.45
Bordeaux mixture, 5-5-100; emulsified oil	11	447	27.1
	15		50.5
Check, brushed but undipped	11	452	41.6
	15		51.5
	21		59.3

tested, it gave maximum protection when applied within the first 36 hours following the brushing. This time interval undoubtedly will vary with atmospheric conditions.

To determine whether the effectiveness of the borax dipping solution was reduced by use, 2 bushels of brushed sweet potatoes were treated in a 50-gallon batch of borax, sodium hydrogen carbonate, emulsified oil, and water which had already been used to treat 450 bushels of sweet potatoes. For comparison, 3 bushels of comparable sweet potatoes were treated in a similar dipping material that had been freshly prepared. Both lots of sweet potatoes were packed wet and stored together with 2 bushels of brushed but undipped (check) sweet potatoes for 11 days at a temperature varying from 57 to 62° F. At the end of this period it was found that 2.1 per cent of the sweet potatoes that had been treated in the previously unused solution were affected with soft rot, as compared with 6.7 per cent of those that had been dipped in the much-used dipping material, and 64.8 per cent for the undipped potatoes. Apparently the fungicidal efficiency of the dipping material is reduced somewhat through usage. In view of this fact and of the inexpensiveness of the

Fig. 1. Undipped Sweet Potatoes 11 Days After Brushing Show a High Percentage of Soft Rot

Left, rotted potatoes; right, healthy potatoes (see table 2)

dipping solution, it is suggested that a 50-gallon batch be discarded and replaced with a fresh solution after treating about 300 bushels of potatoes.

Improved Appearance.—Of the various formulas tested for dipping, it has been observed that all materials that are alkaline deepen the golden color of the skin of the potato, and conversely, acid solutions lighten the color. Apparently there is a pH indicator in the skin of the potato, which makes it possible to improve the appearance of the light-colored potatoes that are produced in light-colored acid soils.

Materials that have been found most satisfactory in improving the color of sweet potato skins are borax, sodium hydrogen carbonate, and Sulfocide. Lime-sulfur solution also deepens the color, but potatoes treated in this material may have a dusty appearance. Although water solutions of these

FIG. 2. SWEET POTATOES BRUSHED AND DIPPED IN A MIXTURE OF BORAX, SODIUM HYDROGEN CARBONATE, EMULSIFIED OIL, AND WATER SHOW VERY LITTLE SOFT ROT 11 DAYS AFTER TREATMENT

Left, rotted potato; right, healthy potatoes (see table 2)

materials deepen the color of the potatoes, the color change is even more pronounced in the presence of oil.

Of the several formulas that are employed for dipping sweet potatoes, the following seems to be best suited for the dual purpose of protecting against soft rot and of enhancing the appearance; borax, 20 pounds; oil, emulsified or straight; and water to make 100 gallons. If a slightly darker colored potato is desired, 10 pounds of sodium hydrogen carbonate should be added to each 100 gallons of the dipping solution. Where protection against rots alone is desired, or where the oily finish is objectionable, the borax and water are all that is necessary.

In the tests reported here, where an emulsified oil was used, 2 gallons of an 86 per cent summer spray emulsion was used in each 100 gallons of dipping

material prepared. Where a straight oil was used, a light mineral oil (65 to 72 seconds viscosity) was found most suitable.

Although either an emulsified oil or a straight oil is satisfactory for sweet potato processing, emulsified oil is the more satisfactory for use, because it is all added during the preparation of the dip and is distributed evenly throughout the solution. This means that all potatoes treated in such a dip will be uniformly covered with an oily film. Straight oil, on the other hand, concentrates in a surface film, instead of being distributed uniformly throughout the dip. This surface film should be kept intact by the addition, at regular intervals, of more oil.

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